Using a Limited Number of Dermatomes as a Predictor of the 56-Dermatome Test of the International Standards for Neurological Classification of Spinal Cord Injury in the Pediatric Population

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Background: For young children with spinal cord injury (SCI), the sensory exam of the International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI) is long and arduous, often making it impossible to complete. **Objectives:** In this study, we determine whether an abbreviated sensory exam provides comparable information to the full 56-dermatome exam. **Method:** A total of 726 56-dermatome sensory exams were completed with 190 children and youth with SCI ranging in age from 3 to 21 years. The cohort was randomly split into test and validation groups. For the test group, a principal component analysis (PCA) was carried out separately for pin prick (PP) and light touch (LT) scores. From the PCA, a hierarchical cluster analysis was performed to identify the most influential set of 4, 8, 12, and 16 dermatomes. From the sensory exam data obtained from the validation group, a linear regression was performed to compare the limited-dermatome composite scores to the total 56-dermatome scores. **Results:** For both LT and PP, the 16-dermatome test resulted in the best fit (0.86 and 0.87, respectively) with the 56-dermatome test and was comprised of dermatomes from both the left (7 dermatomes) and right (9 dermatomes) sides and at least 1 dermatome from each vertebral region bilaterally (cervical, thoracic, lumbar, sacral). **Conclusion:** A 16-dermatome sensory exam provided a good correlation to the 56-dermatome exam. The shortened exam may be useful for evaluating children with SCI who cannot tolerate the full examination. **Key words:** *neurologic evaluation, pediatrics, spinal cord injury*

The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) [1-3] is the standard method of evaluation to determine the neurological status of persons following spinal cord injury (SCI) and for the classification of the neurological consequence of the injury. The neurological assessments consist of motor, sensory, and anorectal examinations. These assessments provide the basis for classifying the motor level (ML), sensory level (SL), neurological level (NL), severity (complete or incomplete), and the zone of partial preservation (ZPP).[1] Over the past several decades, the ISNCSCI has undergone several revisions to improve its reliability and to standardize both examination and classification techniques.[4-9] The ISNCSCI[1-3] is internationally applied, which provides consistency in the evaluation and classification of SCI, in comparisons of injuries and outcomes across centers, and in the evaluation of neurological recovery and treatment effectiveness.

The sensory examination consists of testing 28 dermatomes on each side of the body for 2 aspects of sensation, light touch (LT) and pin prick (PP; sharp-dull discrimination). LT is tested with a tapered wisp of cotton stroked once across an area of skin not to exceed 1 cm, whereas PP is performed with a disposable safety pin stretched apart to allow testing on both ends.[2] According to the 2003 ISNCSCI,[1] these 2 sensory modalities were chosen for required testing, because they

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reflect transmission of information through different tracts of the spinal cord and they can be readily tested in all dermatomes of the body.

In our experience, administering the sensory component of the ISNCSCI to children and youth with SCI can be arduous and time consuming for both the examiner and patient. In a previous study,[8] we found that the majority of subjects under 10 years of age were anxious during the PP exam. Anxiety surrounding the PP test, the inability to remain focused, and the inability to provide appropriate responses over the entire test were prominent among the reasons for not completing the examination. This provided impetus for determining whether an examination consisting of a subset of the 56 dermatomes may provide adequate information on the overall sensory status of the patient.

To our knowledge, there has been 1 report on a shortened sensory exam by Marino and colleagues.10 Using full exams from 1,213 adult patients, they preselected[10] dermatomes (C4, C6, T4, T6, T10, L2, L4, S1, S3) spaced along the 28-dermatome scale and found that the shortened test provided an excellent estimate of the full exam.

The work of this article is part of a larger research effort to establish the utility of the ISNCSCI in children and youth.[8,11-13] It reports on the derivation of a limited dermatome test based on a principal components analysis (PCA) using 726 full sensory exams with 190 children and youth with SCI.

Materials and Methods

Research design

This was a multicenter, prospective study using a cross-sectional design. The study protocol, consent, assent, and Health Insurance Portability and Accountability Act (HIPAA) forms were all reviewed and approved by the institutional review boards at both participating sites (Philadelphia and Chicago Shriners Hospitals for Children). For subjects younger than 18 years of age, written informed consent was obtained from parents or legal guardians. Participants between 7 and 17 years of age also provided written informed assent; participants older than 18 years of age and older provided their own written consent. For participants who spoke Spanish as their primary language, an interpreter assisted in the informed consent process and testing procedures.

Sample

A convenience sample of 190 subjects was included in this analysis. To be included in this study, participants needed to be between 3 and 21 years of age with a chronic SCI (≥3 months post injury) and be able to demonstrate the cognitive ability to accurately respond to ISNCSCI test instructions. Children were not invited to participate in the study if they had a traumatic brain injury or a pre-existing condition that limited their ability to cognitively participate in motor and sensory testing or if they required mechanical ventilation that inhibited expressive communication during testing. In addition, 27 subjects, all between 3 and 8 years of age (median age 5 years), were too young to understand test instructions or were unable to finish the examination and were excluded from this analysis. **Table 1** describes the demographics of the study participants, and **Figure 1** illustrates the distribution of injuries among neurological levels.

The sensory examination techniques and classification methodology of the ISNCSCI were performed based on the standards published in 2003.[1,3] Each of the participants had a minimum of 2 neurological exams (performed by 1 examiner) but as many as 4 neurological examinations (2 exams each performed by 2 different examiners). Collectively, there were 7 examiners who, prior to data collection for this study, participated in formal training in the examination techniques12 and classification methodology.[11]

Data management

Scores were documented immediately throughout the examinations using the ISNCSCI form that was modified, with permission, for this study. For each subject, scoring and classification were performed by trained raters and confirmed by a computer algorithm.[14] If a classification discrepancy arose between the rater and the algorithm, a senior investigator (M.J.M.) determined the correct

Table 1. Study demographics

Demographics	Mean ± SD or n (%)
Average age, years	
Male	14.9 ± 4.0
Female	14.2 ± 4.5
All	14.6 ± 4.2
Gender	
Male	111 (58%)
Female	79 (42%)
ASIA Impairment Scale[a]	
A	99 (53%)
B	41 (22%)
C	25 (13%)
D	23 (12%)
Severity	
Complete – Paraplegia	61 (32%)
Complete – Tetraplegia	36 (19%)
Incomplete – Paraplegia	34 (18%)
Incomplete – Tetraplegia	59 (31%)
LOI	
Paraplegia	95 (50%)
Tetraplegia	95 (50%)

Note: ASIA = American Spinal Injury Association; LOI = level of injury.

[a]Two subjects could not be classified. One subject had a concomitant long limb and another had contractures that prevented classification.

classification using the guidelines from the test manual1 and in consultation with current and past chairs of the Neurologic Standards Committee of the American Spinal Injury Association. Data underwent double entry into a secure database by research assistants who were blinded to the study.

Data analysis

Children were randomly split into 2 equal groups (test and validation). For the test group, a PCA using varimax rotation was carried out separately on LT and PP using Spearman correlations as input derived from 56 dermatomes (left and right) scored as 0, 1, or 2. Two independent factors were retained from each factor analysis for both LT and PP encompassing 64% and 56% of the total variance, respectively. From the PCA, a hierarchical cluster analysis was performed to identify the most influential and discriminating groups of 4, 8, 12, and 16 dermatomes. Using the sensory exam data from the second group for validation, a linear regression was performed to compare the limited-dermatome composite scores generated from the PCA to the total 56-dermatome sensory scores.

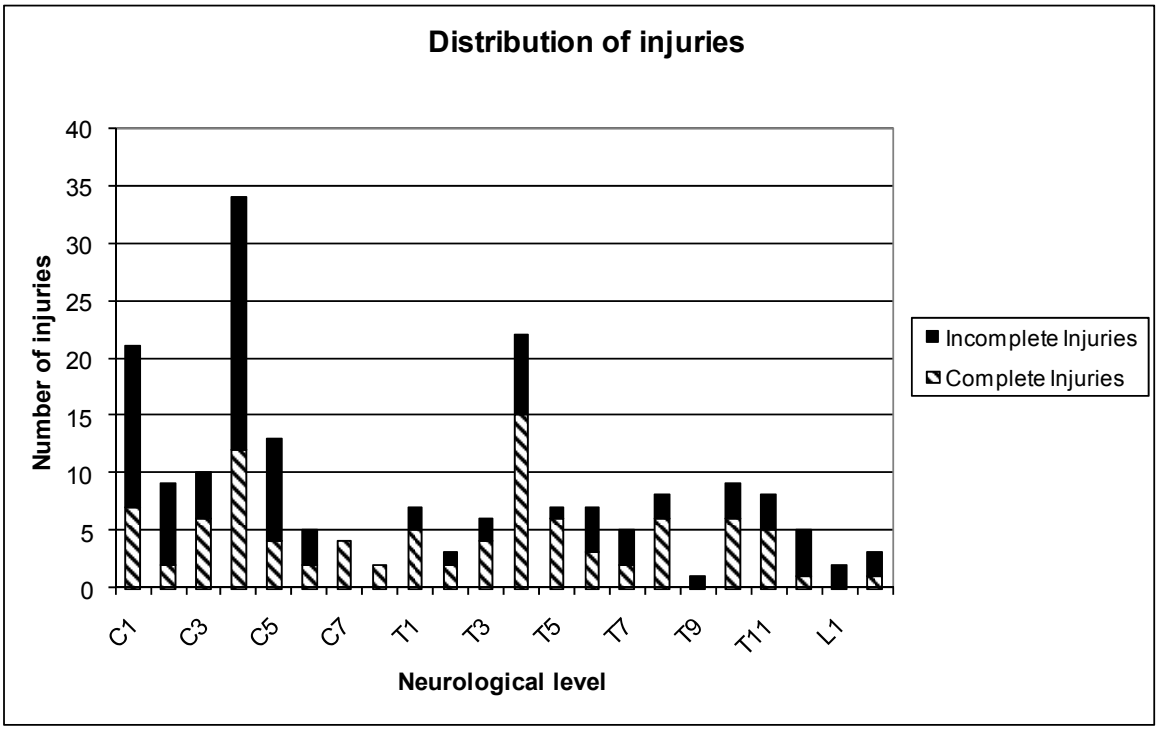

Figure 1. Distribution of injuries among all subjects.

Table 2. Demographic comparison of test and validation groups

Category	Item	Test group (n = 95)	Validation group (n= 94)	*P*
Severity	Complete	47	50	.66
	Incomplete	48	44	
Injury level	Paraplegia	52	43	.23
	Tetraplegia	43	51	
Mean age, years	–	14.1 ± 4.38	15 ± 4.0	.17
Mean LT score	–	56 ± 26	51 ± 25	.26
Mean PP score	–	47 ± 24	43 ± 24	.36

Note: Each subject was randomly assigned to a group. There was no statistically significant difference between the 2 groups in any category. Severity and injury level were compared using Fisher exact test, and age, light touch (LT), and pin prick (PP) scores were tested using *t* test.

Results

There was no statistical difference in the composition of the test and validation groups of children with SCI in terms of injury level, severity, age, or LT and PP scores (**Table 2**).

From each of the 2 factors retained from the PCA, adjacent dermatomes in 2 distinct areas of the spine emerged as most important within each factor for both LT and PP: the lower cervical/upper thoracic dermatomes (factor 1) and lower lumbar/upper sacral dermatomes (factor 2). The shortened dermatome tests were then developed by selecting the dermatomes with the greatest factor loading (ie, greatest correlation) equally from each factor. For example, for the 4-dermatome test, 2 dermatomes were selected from factor 1 and 2 from factor 2. In this way, the shortened dermatome sets retained symmetry with regard to the 2 general dermatome areas of interest and each side of the body. **Tables 3** and **4** show the specific dermatomes determined from the cluster analysis for each of the abbreviated tests.

From the validation test, coefficients of determination (percent fit) for LT were 0.80, 0.82, 0.85, and 0.87 for the comparison of the 4-, 8-, 12-, and 16-dermatome tests, respectively, to the full exam. For PP, the coefficients of determination were 0.81, 0.84, 0.86, and 0.86 for the comparison of the 4-, 8-, 12-, and 16-dermatome tests, respectively, to the full exam. For both LT and PP, the 16-dermatome test resulted in the best fit and was comprised of dermatomes from both the left side (7 dermatomes) and right side (9 dermatomes) and at least 1 dermatome from each vertebral region bilaterally (cervical, thoracic, lumbar, sacral).

Discussion

This study evaluated how well the total scores of the 56-dermatome LT and PP tests of the ISNCSCI could be predicted from testing a limited number of dermatomes using test data from 190 children and youth with chronic SCI. The dermatomes for the shortened exams were developed based on a PCA of sensory data from half the cohort (test group). A linear regression analysis was then performed with the other half of the cohort (validation group) comparing each of the shortened tests to the full examination. For both PP and LT, correlations between the full examination and the shortened 4-, 8-, 12-, or 16-dermatome tests were between 0.79 and 0.87, suggesting a good fit to the 56-dermatome examination. The 16-dermatome test resulted in the best fit in both cases.

This study was motivated by the desire to shorten the ISNCSCI sensory examination time for children in a way that would still be predictive of the total sensory score. During the course of this study, no children under the age of 4 (n = 7) and 20 of the 48 (42%) children who were between 4 and 8 years old were unable to complete the

Table 3. Dermatomes determined by principal component analysis to be most influential for light touch

Right		Left	
C2		C2	
C3		C3	
C4		C4	
C5		C5	
C6		C6	
C7	**16**	C7	**16**
C8	**8**	C8	
T1	**4**	T1	**8**
T2	**4**	T2	**12**
T3	**12**	T3	
T4		T4	
T5		T5	
T6		T6	
T7		T7	
T8		T8	
T9		T9	
T10		T10	
T11		T11	
T12		T12	
L1		L1	
L2		L2	**16**
L3	**12**	L3	
L4	**8**	L4	
L5		L5	**4**
S1		S1	**8**
S2	**12**	S2	**4**
S3	**16**	S3	
S4-5		S4-5	

Note: The number adjacent to the dermatome indicates the dermatome set. For example, the 4 dermatomes with a "4" next to them indicate those belonging to the 4-dermatome exam. Subsequent dermatome sets include the dermatomes from the previous set plus 4 additional dermatomes.

Table 4. Dermatomes determined by principal component analysis to be the most influential for pin prick

Right		Left	
C2		C2	
C3		C3	
C4		C4	
C5		C5	
C6		C6	
C7		C7	
C8	**8**	C8	**12**
T1	**4**	T1	**16**
T2	**4**	T2	**16**
T3	**8**	T3	
T4	**12**	T4	
T5		T5	
T6		T6	
T7		T7	
T8		T8	
T9		T9	
T10		T10	
T11		T11	
T12		T12	
L1		L1	
L2		L2	
L3		L3	**4**
L4		L4	**4**
L5	**12**	L5	**12**
S1	**16**	S1	
S2	**12**	S2	
S3	**8**	S3	**8**
S4-5		S4-5	

Note: The number adjacent to the dermatome indicates the dermatome set. For example, the 4 dermatomes with a "4" next to them indicate those belonging to the 4-dermatome exam. Subsequent dermatome sets include the dermatomes from the previous set plus 4 additional dermatomes.

full sensory examination. Test anxiety, especially concerning the PP test, and inability to remain attentive and provide responses over the course of the exam have been noted as primary obstacles to test administration for young children.[8]

A shortened test score that is a good fit to the total test score could allow the clinician to obtain relevant information on the child's sensory status that may otherwise not be possible. Such an examination would also save time for the patient and therapist, may relieve anxiety for the young patient, and may have an ancillary benefit as the child may be more attentive during a shortened examination and thus provide more accurate responses as compared to those obtained with the 56-dermatome test.

In the only other comparable study, Marino et al[10] preselected 10 dermatomes bilaterally to create a 20-dermatome test (C4, C6, C8, T4, T6, T10, L2, L4, S1, S3) and compared those scores to the full examination using data from approximately 1,200 adults with SCI. A graded response model was applied to half of the cohort to calibrate the sensory items and then maximum likelihood estimates of sensory function were developed using the other half of the study group. For both PP and LT, the 20-dermatome scale predicted greater than 97% of the variance, indicating that the shortened test was

an excellent predictor of the long exam. Rather than preselecting the dermatomes, we thought it most reasonable to determine the dermatomes based on the PCA using data combined from both the left and right sides. Based on our experience, depending on the age of the child and the purpose of the exam, we thought that between 4 and 16 pin pricks would be the most that many children would allow before losing interest in the exam.

For both PP and LT, the specific dermatome subsets that resulted from the PCA were clustered in the lower cervical/upper thoracic and lower lumbar/upper sacral regions, bilaterally (**Tables 3** and **4**). The lower cervical/upper thoracic region of interest may have been influenced by the fact that approximately half of all injuries were cervical and another 20% of injuries were upper thoracic (between T1 and T4). It stands to reason that regions of partial sensation important to the person's overall sensory presentation would be from dermatomes corresponding to areas concentrated around the regions of injury. For both PP and LT, all but 3 (T3, T4, S3) of the dermatomes involved in the shortened tests were located on the upper or lower extremities versus the torso or neck regions. In particular, dermatomes associated with both the hands (C7, C8) and feet (S1, L5, L4) emerged as important regions from the PCA. It is known that in general there is a heightened awareness of the central nervous system to mechanical stimulation in the hands and feet (as compared to the trunk) due to a high density of mechanoreceptors and greater representation of these areas in the somatic sensory cortex.[15] For children with residual sensation in the extremities, they perhaps were best able to distinguish LT and PP stimuli of the hands and feet.

In this study, the demographics of the cohort of children and youth with SCI appear to be typical for this age group in terms of injury level and severity. Data from an epidemiological study of approximately 10,700 children with SCI[16] indicated that of children between the ages of 6 and 21, roughly 43% of SCIs were incomplete and 52% of all injuries were cervical. As shown in **Table 1**, in this study cohort, 49% were incomplete and 50% of all injuries were cervical.

The shortened sensory tests could be used as a guide for clinicians faced with the prospect of a child who will not tolerate the full sensory examination. For example, they could start with the 4-dermatome test and expand to an 8- or 12-dermatome test as the child could tolerate. All the shortened tests provided a good fit to the 56-dermatome test (0.79 or better), so there would not be a great loss in predictability if only the shortest test could be tolerated. The shortened sensory exam may also provide an alternative to the full 56-dermatome exam for the recommended routine neurological monitoring of children of all ages. Too often, the ISNCSCI examinations are not performed during outpatient visits due to the excessive time requirements needed for sensory testing. An abbreviated test may be an acceptable outpatient evaluation with respect to the time requirements while providing an acceptable estimation of the full 56-dermatome examination.

These shortened sensory examinations require further evaluation, including whether they are sensitive to neurological change. These tests also do not provide within-test flexibility to include or exclude dermatomes based on the characteristics of the individual patient. In the future, an ideal shortened exam would provide the clinician with flexible guidelines to adjust the number and location of examination sites based on the initial findings, time since injury, and the child's age and attentiveness, among other factors and at the same time provide strong predictive ability. It is likely that adoption of an abbreviated sensory test would require re-evaluation of the current method used for classification. To illustrate, without testing of all of the cervical and thoracic dermatomes, the current technique used to determine motor levels in regions without key muscles would not be possible. Also, the current method does not determine injury severity (complete vs incomplete injury). Hence, we are not recommending immediate use of the abbreviated sensory examination as we understand the implications. However, we continue to seek possibilities for the ISNCSCI or modified ISNCSCI in children.

Conclusion

This study demonstrated that testing a limited number of dermatomes as a predictor of the 56-dermatome sensory test of ISNCSCI is feasible in the pediatric population. Although there are

limitations with the utility of the shortened exam, the further development of this shortened exam may allow us to obtain relevant information on children's sensory status, while saving time for the patients and therapist, and to alleviate some of the stress and anxiety that children experience during the 56-dermatome test of the ISNCSCI.

Acknowledgments

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